
Oil PROCESSING Program

*Advancing
Refinery Science
and Technology*



OIL AND GAS RD&D PROGRAMS

The U.S. refining industry contributes significantly to our Nation's economy, producing refined products valued at over \$110 billion per year and employing about 104,000 people.

Our Nation's technology leadership positions U.S. companies to export refining technologies and equipment to rapidly growing international markets. Such export opportunities could amount to many billions of dollars by 2010.

The cost of environmental regulations is now undercutting the refining industry's leading edge in oil processing technology and its competitiveness in a world market. According to a recent study by the National Petroleum Council, environmental compliance costs are projected to exceed \$150 billion between 1991 and 2010, including more than \$36 billion for capital equipment to meet current regulations. It also includes an estimated \$5 to \$12 billion to meet expected regulations for particulate matter (PM_{2.5}), ozone, sulfur, and nitrogen, severely limiting available funds to develop and demonstrate new technology and equipment. Since 1994, the refining industry has committed over \$20 billion to capital equipment for improving environmental performance. Such equipment has absorbed between 75 and 90 percent of total capital expenditures to meet environmental regulations, especially the Clean Air Act Amendments of 1990.

New refinery technologies can equip the industry to prevent pollution and protect the environment more efficiently than is possible with today's costly retrofit approaches. New technologies can handle the challenges posed by lower quality domestic feedstocks, and produce the more complex, high-value product slates that the market now requires. ONGPT's Oil Processing Program has important roles to play in the research and development of such technologies. Program personnel are working closely with the industry to gather the scientific information essential for sound regulatory decisionmaking, as well as developing refining technologies that increase efficiency, decrease costs, and enhance environmental performance.

Oil Processing Program

Advanced crude oil processing technologies are critical to the Nation and to the refining industry.

In the last decade, environmental regulations have had a far-reaching impact on both the processes and products of the U.S. refining industry. Refineries must comply with increasingly stringent emissions and discharge limits on their processes. At the same time, they must meet demands for lighter, high-value finished products, such as gasoline, diesel fuel, jet fuel, and petrochemical feedstocks, whose composition and quality have changed markedly to meet environmental standards. For example, the Clean Air Act Amendments of 1990 require the production and use of reformulated gasoline and low-sulfur diesel. This and other projected changes in the product slate will result in higher storage and transportation costs, added capital expenditures, and product exchange complications. The low-sulfur fuels requirements alone have been estimated to cost each major refinery about \$100 million in new capital costs, not to mention additional operating costs.

Environmental regulations have resulted in the closing of a number of smaller, less efficient U.S. refineries that have been unable to afford the required capital expenditures. These regulations also have made the construction of new refineries in the U.S.

unlikely. Although larger refining operations are expected to remain viable, recent studies suggest that another 10 percent of U.S. refineries may close, resulting in the loss of over one million barrels per day of capacity. With U.S. refineries already operating at near maximum utilization rates, such a loss in capacity exposes U.S. consumers to gasoline price spikes caused by interruption of operations at any one refinery. A recent refinery upset at a major West Coast refinery caused gasoline prices to increase by about \$0.25/gallon in California and \$0.10 to \$0.20/gallon across the rest of the Nation.

The declining quality of crude oil feedstocks compounds the challenges facing U.S. refineries. Crude oil feedstocks, particularly those from domestic sources, are becoming heavier, with rising levels of sulfur, nitrogen, and heavy metals. Using present technology, the processing of heavy crude yields unacceptably high levels of low-value residual oils, coke by-products, and wastes. As the market for residual oils declines, more processing is necessary to create higher-value products, producing even more coke. Disposal options for this coke, which contains metals, are becoming increasingly limited.



Government Role

Perhaps the most important role of the Federal Government is to assure its citizens an acceptable quality of health, environment, and safety. However, at the same time it must balance public needs with respect to a vibrant, growing economy and affordable transportation fuels.

The Government is employing several strategies to meet these goals. A significant and expanding regulatory framework is being promulgated that purports to control emissions from oil refineries and govern the content of the produced fuel slate. The Federal Government has a responsibility to ensure that these regulations are based on sound science.

New, innovative technology to prevent pollution and minimize waste is being developed, with Federal support, to assure that appropriate national levels of environmental quality are achieved without having a decimating effect on the economy or the Nation's standard of living.

While our Nation exported coke in the past, such exports are expected to decline as environmental regulations in foreign countries reduce the economic viability for using these products. Some refineries have mounds of coke at their sites.

Advanced technologies can potentially yield refining processes that greatly reduce quantities of low-value coke, while cost-effectively producing high-value products. With such technologies, our Nation would be able to tap sources for large-scale production of heavy crude in California, Alaska's North Slope, the Gulf Coast, and parts of the Rocky Mountains. An increase in heavy crude production would help to slow the continuing decline in overall domestic oil production.

Unfortunately, at this moment of unprecedented need for oil technology development, industry investments in R&D are declining. A recent trend is for major oil companies to sell refining capacity to independent refiners. Independent refiners typically do not support research facilities to improve or develop new processes. Intense global competition has forced the industry not only to reduce total R&D, but to shift remaining investments away from long-term R&D and toward more immediate services and applied technology for environmental compliance. As a result, few investment dollars are left for R&D on new processing technologies.

This divestiture of refining capacity by the majors has an interesting ramification – the exploration and production portions of the companies are exploring a new concept of increasing the value of their crude before selling it to integrated refineries. Accordingly, these companies are using downstream refining technology to upgrade their produced heavy crude in the production field and to obtain the increased value. Current upgrading consists of partial coking to increase liquid API gravity and decrease sulfur content – the two major parameters in determining discounted prices paid for heavy crude. Bio-upgrading technologies, though undeveloped at this time, have promise for future economical upgrading of heavy crude, including increasing API gravity and decreasing sulfur, nitrogen, and metals. This technology has the additional allure of potential environmental advantages.

At this time, the U.S. oil refining industry continues to lead the world in technology. The industry has developed new refining technologies for preventing pollution and providing the more diverse product slate required for improved environmental performance. U.S. refineries still account for approximately 20 percent of worldwide crude processing capabilities, and the industry as a whole remains the most sophisticated. Nevertheless, the enormous costs the industry faces constrain its abilities to develop the technologies needed to remain competitive. A loss of U.S. technology leadership would also translate into an erosion of the current export strength of U.S. equipment manufacturers serving the global refining industry.

The Role of DOE

Though small in funding, the DOE Oil Processing Program is a vital element of the total U.S. oil processing research effort. Research programs of the major oil companies tend to focus primarily on maintaining throughput and meeting existing environmental regulations, rather than on processing future feedstocks or reducing environmental impacts. DOE's Oil Processing Program supplies key basic science information, particularly on long-range technologies and concepts.

Since the 1940s, DOE has conducted a world class program for fundamental chemistry for refinery processes. Its aim is to identify parameters necessary for efficient refining of crude oil.

Today, as crude oil becomes heavier and contains more sulfur, nitrogen, and heavy metals, these types of data are needed more than ever.

Several shifts in focus have helped to ensure maximum returns for program investments. The program has:

- Increased emphasis on identifying the science and technology necessary for regulators to create and implement science-based, risk-based environmental regulations;
- Increased emphasis on scientific data that can facilitate industry development of new technologies for minimizing waste products and risk to supply during the processing of heavy crude oils; and
- Implemented more vigorous outreach to ascertain industry needs before research is planned and implemented; and worked with groups that have a broad industry coalition, such as the Petroleum Environmental Research Forum (PERF), the Western States Petroleum Association (WSPA), and the National Petrochemical and Refiners Association.

As a result, the program is now positioned to provide the science and technology base to assist the U.S. refinery industry in maintaining its technological edge, its environmental leadership, and its competitiveness in the global marketplace.

Industry Issues

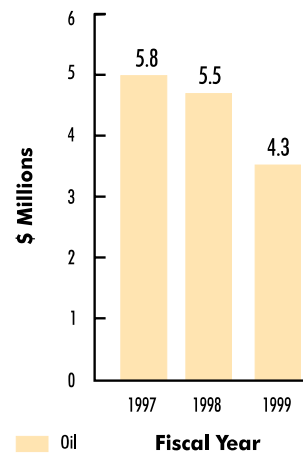
- *Development of catalysts with improved selectivities, yields, and lifetimes*
- *Increased plant and process reliability*
- *Improved energy efficiency of processes and equipment*
- *Improved separation technologies*
- *Development of new approaches to upgrading and refining heavy feeds*
- *Determining performance and environmental characteristics of new hydrocarbon fuel compositions*

Program Benefits

The ultimate impact of DOE's Oil Processing Program is the continued strength of our domestic refining industry and increased production of heavy oil. Measuring the value of the program is difficult, since many of our efforts are in basic science and must be implemented by industry. However, meeting the program goals over the next 20 years will result in:

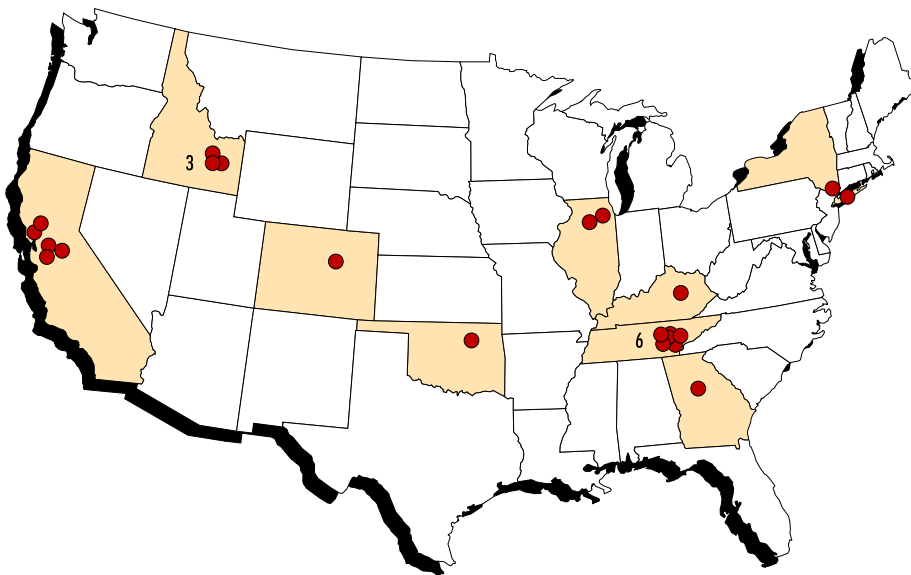
- Decreased oil imports of approximately 50,000 Bbls/day;
- Reduced number of refinery closures to six from EPA estimates of 16;
- Approximately 500,000 Bbls/day of additional U.S. refined products from heavy oil;
- Reduced output of lower value products from 1.2 million Bbls/day to less than 500,000 Bbls/day;
- Cost savings of over \$130 million;
- Reduced carbon dioxide emissions of over 20 million tons; and
- Over 20 million barrels of heavy oil reserves that are more economic to produce.

Oil Processing Program Budget



Project Sites

The Oil Processing Program conducts 22 projects in 9 States.



OIL
PROCESSING

Drivers

- Crude oil supplied to refineries is becoming heavier, while the market requires a product slate that is lighter, with less sulfur and nitrogen and more oxygenates.
- The market for the heavier residues of refined oil has been substantially reduced, thus requiring that the residue undergo further processing before it can be used.
- Environmental regulations are forcing refineries to devote substantially more of their budgets to environmental compliance at the expense of their technology development efforts.
- Proposed environmental regulations (e.g., on particulate matter and ambient ozone concentrations) threaten to significantly increase compliance costs and accelerate the closing of domestic refineries.
- During the past few years, major integrated oil companies have been selling refining capacity to independent refiners at a fraction of the capitalization costs. Independents are less likely to invest in new technologies for improving efficiency and environmental compliance.
- During the past decade, the number of refineries has decreased from 216 to 159, yet throughput has increased from about 14 million to over 15 million barrels per day. Therefore, the potential disruption to fuel supply caused by refinery upset or major accident is much more significant today.

Goals

- Assist the oil industry in maintaining its viability, by developing cost-effective and environmentally-acceptable heavy oil and residual upgrading and refining technologies that will increase the value to the producers, while increasing processing efficiency and reducing environmental impacts.
- Work with industry organizations, government regulators, and other interested parties to generate and transfer new technologies and data that will lower environmental impacts and wastes (including greenhouse gases) in processing the crude oils.
- Serve as a neutral third party between Federal and State regulators and the petroleum industry to develop scientific information on the environmental and health risks of pollutants emitted by the petroleum industry, and provide sound science for the future regulatory framework for domestic refineries.

Strategies

- Work with industry organizations and government regulators on joint projects to continuously generate and transfer new technologies and fundamental data to the refiners and heavy oil producers.
- Communicate with all clients to understand their needs, and continuously plan activities to address those needs while remaining consistent with national priorities.
- Help provide the technologies to prevent formation of pollutants by process modifications and/or unit changes in the refineries, and reduce risk to equipment malfunctions.
- Encourage the development of rational science- and risk-based regulations on upgrading, refining, and downstream operations by providing sound science.
- Identify various pollutants present in petroleum and develop technology to prevent their formation. In keeping with PCAST recommendations, perform research to make fuels that have fewer emissions affecting global climate change.

Oil Processing Program

Measures of Success

By 2010, the DOE-industry partnership will yield:

- Increased crude oil processing efficiencies for processing heavy crude oil, reduced air emissions, and reduced production of residual products.
- New technology for upgrading heavy oil at production sites, returning more value to producers and producing less environmental emissions than current technologies.
- Economic production of cleaner-burning transportation fuels in quantities sufficient to satisfy consumer demand and prevent drastic price increases.
- Reduced dependence on imported oil as a result of increased production of transportation fuels by domestic heavy oil refineries.
- Downward trend in environmental compliance costs as a function of total operating costs for refineries, and increased capital expenditures on technology development.
- Reduction in the number of refinery closings predicted by EPA.



Relationship to Other DOE Programs

On such issues as tank evaporative emissions, spill remediation, and selenium and heavy metals in effluents, the Oil Processing Program conducts research that complements work being done in the Environmental Research and Analysis Program.

The Oil Processing Program also shares areas of mutual interest with Fossil Energy's Coal Programs, e.g., the development of fundamental chemistry for technologies to upgrade heavy oil and convert coal to liquid fuels, and the ambient fine particulate matter program.

Program Areas

DOE's Oil Processing Program focuses on two primary areas to promote science, technology, and environmental leadership in the U.S. refining industry. They are:

- Sound science for environmental protection for air and water quality; and
- Chemical and bio-upgrading research for effective upgrading of heavy crude and reduction of pollutants.

Each of these areas is described in the following pages.

Utilization Rate of U.S. Oil Refineries

Year	Operable Capacity (1,000 Bbls/day)	Input to Distillation (1,000 Bbls/day)	Utilization Rate
1982	17,445	12,176	69.8%
1985	15,671	12,161	77.6%
1990	15,623	13,610	87.1%
1995	15,346	14,119	92.0%
1997	15,620	14,740	94.4%
1998	15,788	15,000	95.0%

Source: *Oil & Gas Journal*, January 25, 1999

Sound Science for Environmental Protection – Air and Water Quality

DOE's Oil Processing Program serves the Nation's environmental objectives in a wide variety of ways. One specific way is to provide sound science for improved regulation that will meet environmental goals, by allowing industry to control those emissions that are actually causing harm to the environment. This saves the industry and consumers money and time.

Representative projects are highlighted below.

Environmental Technology Initiative

To develop a framework of scientifically-based regulations for the refining industry, the EPA has created the Common Sense Initiative. DOE's environmental efforts complement this initiative by applying unique capabilities for generating independent, high-quality scientific data related to oil processing, and the streamlining and improvement of existing regulations and laws.

Working closely with industry and the EPA, ONGPT is developing a prototype multimedia approach that integrates advanced knowledge of toxic chemical management with next-generation refinery design. The intent is to go beyond the retrofitting of technologies to existing refineries, and to comply with specific regulatory requirements. Retrofitting has

commonly proven to be very costly in relation to the actual benefits realized. Instead, the new approach starts with a broader systems perspective that encompasses all aspects of refinery wastes and encourages the development of innovative technologies to achieve environmental goals.

PM_{2.5} Government Working Group

When EPA announced its intention to regulate the quantity of particulate matter less than 2.5 microns in size (PM_{2.5}) in the air, the oil and gas industry requested that DOE develop information to help EPA make decisions based on sound science. As a consequence, DOE organized a working group with representatives from WSPA, CARB, Northeast States for Coordinated Air Use Management, Independent Oil Producers' Agency, Gas Research Institute, Electric Power Research Institute, Empire State Electric Energy Research Corporation, and EPA.

The concept of a working group is predicated on the realization that, while all of the coordinating groups have significant interest in the subject matter, none has the resources to completely and individually develop the necessary scientific information. To date, the Working Group organized and conducted four major meetings where six major research topics were identified:



OIL
PROCESSING



- Characterization of the emissions of oil refineries;
- Instrumentation to accurately measure fine particulates in the field;
- Chemistry of their conversion in the atmosphere to regulated substances;
- Transport of these entities to measuring stations;
- Contribution and effect of various reformulated transportation fuels; and
- Pollution prevention technology at the refineries or oil and/or gas burning power plants.

The participants recognized that the breadth of these research areas is very large and it would take significant resources and many years to accomplish. It was further understood that there is no single mechanism for working together, and members should explore other ways to conduct mutually beneficial research whenever and wherever possible. The group accepted DOE's offer to be the focal point for keeping members informed of relevant research efforts and distributing research summaries. One such research effort is a DOE/API joint project to characterize particulate matter at a refinery in southern California.

Disposal Approaches for Refining Process Water

This project is concerned with injection-well disposal of refining process water. The objective is to characterize the types of contaminants and their concentrations in refinery wastewater, and then to compare it to those in wastewater from exploration and production operations that can be disposed of in Class II wells. Class II wells are easier to permit and about one-third less expensive to construct and maintain than Class I wells, which are presently required for refinery wastewater disposal.

Fate and Transport of Selenium in the North San Francisco Bay

In this project, DOE is assisting the San Francisco Bay Water Quality Board in determining whether low levels of selenium from local refineries pose a health hazard to aquatic life in the Bay. The industry contends that the effluent does not pose a hazard, while the Board has stated its belief that refineries must significantly reduce the concentration of selenium in the effluent discharged into the bay.

Determining the effects of selenium concentrations is complicated by the preexistence of selenium in the Bay's sediment originating from a number of sources, some natural. The Board is delaying new regulation until data from the "fate and effect" study are available.

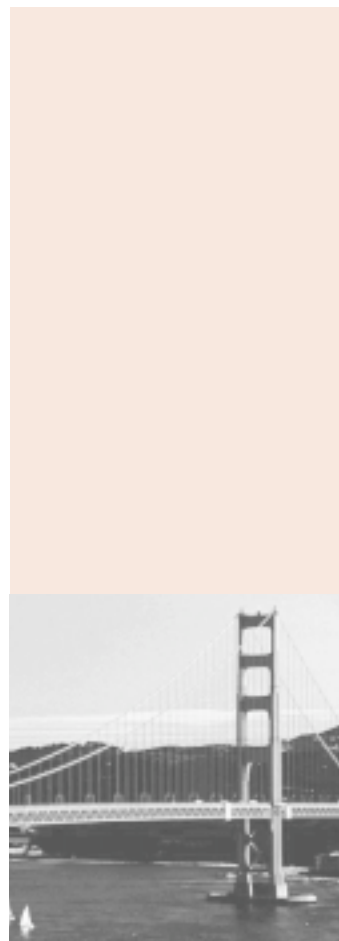
The larger objective of the project is to establish a "fate and effect" protocol, based on scientific study, for assessing the risk of refinery effluent to natural water systems. The output of this research will be crucial in determining the environmental impacts of continued refining of crude oils with a high selenium content, such as those from Kern County, California.

Effects of Residual Hydrocarbons

In response to a request by PERF, ONGPT is sponsoring research to examine the effects on plants and animals of the low levels of residual hydrocarbons left after bioremediation. Specifically, the projects being conducted at Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory are developing an understanding of biotransport of chemicals to support reform of spill cleanup regulations. The 35 oil processing companies within PERF are looking to these projects to address the issue of "How clean is clean?"

Study of Refinery Effluents and Treatment Alternatives

In this two-part project, DOE is collaborating with the Western States Petroleum Association. The first part of the project will determine background levels of heavy metals in Puget Sound, providing data for regulations establishing acceptable heavy metal concentrations in the effluent of five refineries.



The second part of the project will evaluate and demonstrate low-cost analytical techniques recently developed at Pacific Northwest Laboratory (PNL) for performing highly accurate analysis of ultra-low concentrations. This will be followed by assessment of the potential for utilizing technology developed at PNL to minimize or utilize the waste from the biotreatment of refinery waste. One process to be investigated was originally developed for the reuse of biosludge in land farms. While reuse of municipal biosludges in land farms is common, refinery biosludges present different characteristics, liabilities, and economics. This study will report on potential applications and obstacles, and provide recommendations for overcoming problems.

In another process to be evaluated, acid is added to the biosludge stream from a wastewater treatment facility, and the stream is heated and placed in a hydrolysis reactor. This acid hydrolysis process reduces solids in the resulting stream by 50 to 90 percent. The remaining solids are much easier to filter and de-water, and the amounts of biosolids and water sent to a landfill or incinerator are greatly reduced. The project will provide data for a conceptual design of the processing equipment.

Another biochemical project targets remediation of soils whose quality has been reduced by petroleum hydrocarbons. Three alternative remediation approaches are being compared: (1) "no action," or simple weathering; (2) bioremediation, in which nutrients or surfactants are introduced into tainted soils; and (3) phyto-remediation, where plants growing in such soils remove, contain, or biodegrade pollutants. The project will extend the database on toxicity of petroleum products in different soils, and determine which remediation approach achieves the lowest ecological risk for the least cost.

Success Story

Petrochemical Company Increases Yields Six-Fold

Petrochemical companies typically use estimated crude oil property data for design of plant processes when actual data are not available. One polymerization reaction was designed and operated as a commercial plant using such estimates. Compounds being studied by DOE for oil processing corresponded with some of the intermediate reaction products. As this data was released, the company realized that their estimates had large errors. After recalculation using DOE property data, the process yields were increased six times by changing temperature, pressure, and flow rates with no capital investments. This was also accompanied by decreased volumes of waste products.

Chemical and Bio-Upgrading Research for Effective Upgrading of Heavy Crude and Reduction of Pollutants

The DOE's Oil Processing Program also serves the Nation's environmental objectives for producing and utilizing more reserves of heavy oils, by developing fundamental scientific data to facilitate the development of effective refining technologies that reduce environmental emissions. Because processing of heavy crude is associated with increased emissions, DOE's Program has focused on technologies to upgrade heavy oils and reducing those emissions. Efforts include the identification of the constituents of heavy crude to prevent pollution formation during processing or subsequent use.

Integrated oil companies are separating into upstream and downstream components. Many companies are selling refineries to independents. Further, many companies only produce oil, and even integrated companies sell or trade crude, seldom refining their own produced crude. This has led to another use of upgrading technology, that of production companies upgrading their heavy crude to avoid the pricing penalties for low API gravity and high sulfur. This is being practiced in California and Venezuela (by U.S. companies) before

crude shipment to the U.S. Fundamental chemistry and bio-upgrading technology projects will lead to higher-value crude, making it more economical to produce our heavy crude.

In the National Petroleum Council's 1995 study, *Research, Development and Demonstration Needs of the Oil and Gas Industry*, the industry identified areas where research efforts are needed to develop the science and technology foundation required to help the U.S. refining industry. These recommendations were valuable in formulating DOE's Oil Processing Program.

The research areas included new approaches to refine heavy feeds, improvements in the energy efficiency of processes, development of catalysts with improved selection and yields, improvements in plant and process reliability, and research in new separation technologies.

Examples of chemical and bio-upgrading science and technology related activities, designed to meet these industry needs, include the following projects.

Success Story

Refiners Achieving 95 Percent Efficiency

A database of chemical and physical properties was developed, with emphasis on the properties of material in the gasoline fraction, i.e., normal and branched paraffins, alkyl-cyclopentanes and -cyclohexanes, alkyl-benzenes, and sulfur-containing compounds. These data for light petroleum, containing a relatively narrow set of classes of compounds, have permitted the design of processes to produce desired products with high efficiency. The database has become part of the permanent literature that continues to be used with confidence within the industry, in process design and development, in changing product slates, in changing crude input, and in safety calculations. The result is the modern refinery, with an overall energy efficiency of 95 percent when refining light petroleum.

Fundamental Chemistry of Heavy Oil Components

The process engineering properties of heavy oil components will provide the basis for designing efficient process units and setting optimum process conditions for refining heavy crude. Fundamental chemistry data developed for light oil components have allowed refineries to achieve current high efficiencies. Current studies on heavy oil components are expected to produce data that will allow the Nation's refineries to continue to operate at maximum efficiency while minimizing pollutants.

Predicting the Physical Properties of Hydrocarbons

The relationship between the molecular structure of hydrocarbons and their fundamental chemical properties (such as boiling point, melting point, and viscosity) is essential for efficient refining. A feasibility study now underway will develop and validate a method for computational prediction of boiling point distributions for hydrocarbons with given molecular formulae.

Processing Heavy Crude Oil and Residue

Large refineries currently utilize coking as the principal method of upgrading heavy crude oils. Several research projects seek to aid small producers in California, by converting low grade heavy oil and residuum to higher grade material that can be used as a refinery feedstock. Technologies being investigated include pyrolysis and fluidized-bed conversion. Development work is directed at units that could be installed in the production site at lower capital costs. This has considerable interest for smaller companies.

Success Story

Biochemical Processes for Upgrading of Crudes

Experimental observations have led to the development of biochemical processes to convert crude oils. DOE-supported applied biotechnical research at Brookhaven National Laboratory has identified five major applications in the upstream and downstream oil processing industry. They all address the reduction of impurities from crude oil. Particular attention has been given to oils that hold promise, such as those found in California, e.g., Monterey-type, Midway-Sunset, Honda crudes, and other immature and biodegraded types.

Current research shows that biochemical processing results in a significant decrease in sulfur, nitrogen, and trace metals contents of oils, and makes possible conversion of heavy ends to lighter hydrocarbons, and bioconversion of oil wastes for recycling. Biochemical upgrading of petroleum can raise the quality of oil with: 30 to 35 percent reduction in sulfur contents, 30 to 40 percent reduction in nitrogen content, and 40 to 80 percent reduction in nickel and vanadium content. Comparable reduction of other metals (e.g., arsenic, selenium) is also possible. Based on sulfur removal alone, economic analysis models project a feasibility of a net realization of 65 cents per barrel of oil.

Inorganic Membrane Development

DOE researchers are exploring the use of inorganic membranes to separate high-value hydrogen from low-value refinery gases (hydrogen is a key, but an expensive reactant for upgrading of heavy petroleum). Theoretically, the separation would allow the hydrogen to remain on the high-pressure side of the membrane, while separating the other gases to the low-pressure side. This reduces the cost of recompressing the recycled hydrogen. Cost savings at the refinery could amount to \$1.2 billion/year when fully implemented in the U.S. alone. Recycling pure hydrogen also would change the reactant mix, effectively driving the reactions toward the desired products. The result will be an increased yield of light, high-value products, and a considerable reduction of low-value coke produced.

Refiners have long used organic membranes as a reliable and inexpensive way to recover hydrogen for use as a fuel. Inorganic membranes, however, promise far more economical recovery of the hydrogen for subsequent use in processing. These membranes are much more rugged, can be operated at higher pressures and temperatures, and can deliver very high separation factors and permeances. The project, which builds upon membrane

technology used to separate nuclear isotopes, represents the first instance of declassified nuclear technology in this area being transferred for an industrial application.

Upgrading Research

Idaho National Engineering and Environmental Laboratory is investigating the use of a submerged reactive plasma process to react natural gas with heavy crude to reduce the viscosity of oil for improved transportability.

Advanced Bioprocessing Concepts

Advanced bioprocessing concepts could gain increasing importance in energy transformations and conservation, particularly in processing fuels or energy-rich chemicals. Work conducted at several National Laboratories has shown that crude oils can be biochemically converted to lighter oils through removal of heteroatoms, thus reducing sulfur, trace metals, and nitrogen contents. One current research project utilizes biocatalysts to implement a new concept of emulsion-phase contacting carried out in a bioreactor. This research is being conducted with multiple industrial partners to ensure that the technologies developed are quickly transferred to commercial application.

Research also is underway to develop cheaper and more complete biochemical methods for removing nickel and vanadium from heavy crude oil before it enters the refinery. This approach would reduce the costs of recovering and disposing of metals from the refined product. It would also enhance processing of the crude, while reducing environmental consequences.

Another project is developing benchmark costs that must be achieved by novel biochemical processes if they are to become commercially feasible. Analyses have been completed for sulfur reduction processes, and similar analyses are being carried out for nitrogen compounds and metals processes.

**DRILLING &
COMPLETION**

**DIAGNOSTICS
& IMAGING**

**RESERVOIR
EFFICIENCY**

**RESERVOIR
LIFE**

**GAS
STORAGE**

**ENVIRON-
MENTAL**

**OIL
PROCESSING**

**GAS
PROCESSING**

**MODELING &
ANALYSIS**